FACTORS INFLUENCING FREIGHT TRUCK ROUTE SELECTION

Freight Characteristics Influencing the Ratio of Freight Truck Expressway Use

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ABSTRACT

This article details how freight characteristics influence freight truck route selection. Specifically, relationships between the ratio of freight truck expressway use and four factors that describe freight characteristics were analyzed; the four factors are transport distance, delivery time specification, facility type from which freight is shipped, and freight volume. Based on the results of this analysis, we developed a generalized logit model that predicts the ratio of expressway use from the above factors, helping us understand how the trend toward more sophisticated freight transport will influence freight truck route selection in the future.

1. INTRODUCTION

Route selection models for cars are often developed with a particular emphasis on traffic conditions determined by the geometric factors of roads, such as congestion speed and maximum traffic volume. However, freight trucks must select routes taking into account not only traffic conditions but the characteristics of the freight that they are transporting. For example, trucks are more likely to choose expressways if the time of delivery is specified, as doing so enables punctual arrival at their destination; in contrast, general roads often cause large delay in delivery due to unexpected congestion. If a truck is carrying perishables, or other goods that must be kept chilled, it is more likely to take expressways to shorten travel time.

This article discusses the relationships between freight characteristics and freight truck route selection in which the ratio of expressway use was used as an index of freight truck route selection.

2. SUMMARY OF THE DATA USED

This study employs data obtained from the Commodity Flow Census, which has been conducted every five years since 1970 to investigate actual freight movement throughout the country. The census surveys such items as those shown in Table 1 regarding individual freight shipped from subject offices during three specific days in the census year. An Outline of the census and the data obtained from it are shown in Table 1 and Table 2. Expressway networks in Japan are shown in Figure 1.

The analysis was conducted using 322,662 records of freight transported by trucks between prefectures; these records appear at the bottom in Table 2. More than half of the records lack information on whether or not the freight was transported via expressway, as the survey was conducted for consignors, who are unlikely to know the actual transport routes, rather than for forwarders.

Table 1 Outline of the Commodity Flow Census

Outline of the census	
Date of survey	18-20 October 2005 (three consecutive weekdays)
Subjects surveyed	Consignors of 21,763 offices in four industries: mining, manufacture, wholesale, and warehouse (This accounts for 3.2% of the total number of offices in the four industries)
Freight surveyed	Raw materials, products, and merchandise that are transported from and to the subjects surveyed (shown above)
Items surveyed (examples)	
Detailed freight types	85 types: fruit, precision instruments, clothing, etc. (these 85 types are categorized into nine freight types)
Primary means of transportation	12 categories: trucks(5), railways(2), ships(3), airplanes
Relay facility	Fill in the name of the railway station, port, airport, or wholesale market
OD of freight transport	Fill in the address at the municipal level
Expressway use	Used or not-used
Interchanges	Fill in the name of interchanges used
Delivery time specification	Hour specified, AM/PM specified, date specified, no specification
Facility type from which freight is shipped	Refrigerator warehouse, open warehouse, etc.

Table 2 Outline of data used (number of records)

Total number of records	1,126,545	*100.0%*	
Export	11,883	*1.1%*	
Domestic	1,114,662	*98.9%*	*100.0%*
Primary means of transportation: ship or railway	5,473		*0.5%*
Primary means of transportation: truck	1,109,189	*100.0%*	*99.5%*
Transported within the prefecture	329,997	*29.8%*	
Transported between prefectures	735,226	*66.3%*	*100.0%*
Unclear whether or not expressways were used	412,564		*56.1%*
Clear whether or not expressways were used	**322,662**		*43.9%*

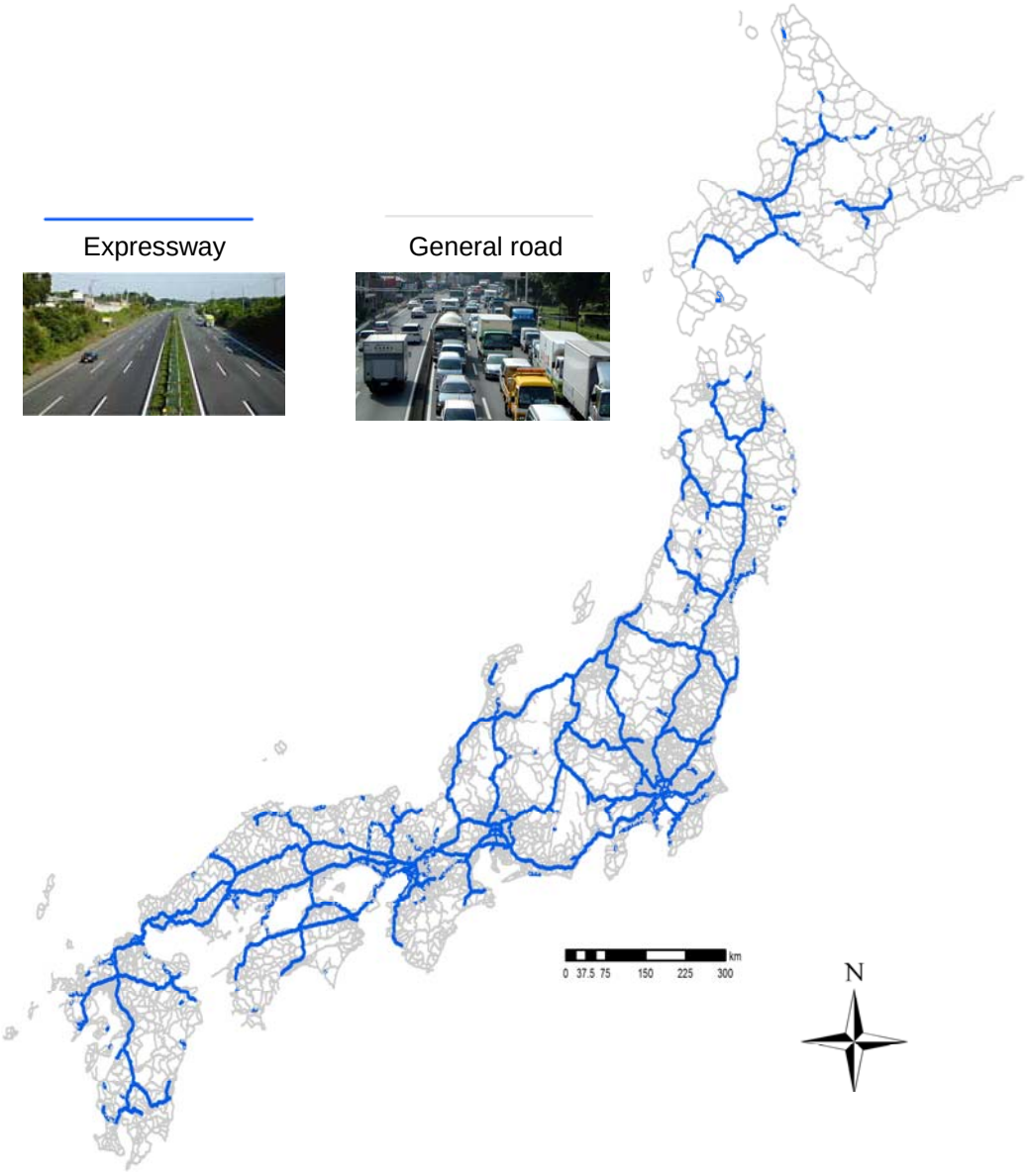


Figure 1 Expressway networks in Japan

3. RELATIONSHIPS BETWEEN THE RATIO OF EXPRESSWAY USE AND FREIGHT CHARACTERISTICS

Figure 2 shows average ratios of expressway use by 100 kilometer distance category for nine freight types, indicating that, for the most part, the ratio of expressway use increases until 500 km and then becomes flat for all nine freight types. Clear differences in the ratio of expressway use were observed among these types; the ratio in Agriculture and Fishery is higher, while the ratio in Mining is especially low. The ratio of expressway use in Forestry and Mining are shown for only distance categories of 500km and below, as the census was unable to obtain a sufficient number of records for distance categories of above 500km.

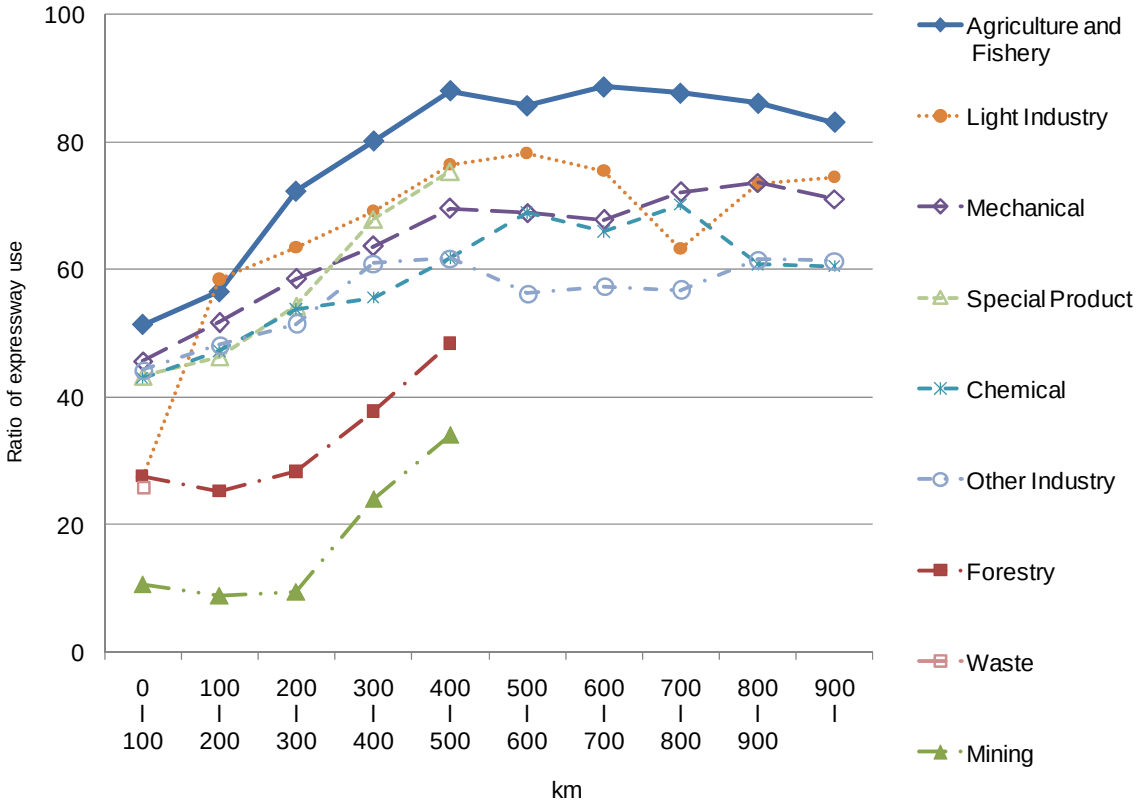


Figure 2 Average ratios of expressway use (for nine freight types)

1) Freight Shipped from Refrigerator Warehouses

The ratio of expressway use in the Agriculture and Fishery industry is the highest among the nine freight types over all distance categories except 100-200km. This can be attributed to the hypothesis that the ratio of expressway use of perishables such as raw fish, for which express transport is preferred in order to preserve freshness, is high, pushing up the overall ratio of expressway use in Agriculture and Fishery, which partly consists of perishables. In particular, an even higher ratio of expressway use is expected for transport by trucks equipped with a refrigerator or freezer because of a greater incentive to shorten transport time in an attempt to conserve energy during transport.

In order to test this hypothesis, the ratio of expressway use for freight shipped from refrigerator warehouses was compared to that of freight shipped from other facilities. As shown in Figure 3, the former showed a higher ratio of expressway use than the latter. As shown in Table 3, the results of a Z-test using Equation 1 tells us statistically significant evidence of differences in the ratios of expressway use at a 0.1% confidence level; therefore, trucks carrying freight shipped from refrigerator warehouses are more likely to use expressways.

Figure 3 Ratio of expressway use
(Freight shipped from refrigerator warehouses v.s. Freight shipped from other facilities)

$$Z = \frac{P_a - P_b}{\sqrt{P_{average} \times \left(1 - P_{average}\right) \times \left(\frac{1}{N_a} + \frac{1}{N_b}\right)}} \quad (1)$$

P_a: Ratio of expressway use for freight shipped from refrigerator warehouses
P_b: Ratio of expressway use for freight shipped from other facilities
$P_{average}$: Average of Pa and Pb weighted by the number of samples
N_a: the number of samples of freight shipped from refrigerator warehouses
N_b: the number of samples of freight shipped from other facilities

Table 3 Result of significance test

km	Ratio of expressway use			Number of sample		Z value	
	P_a	P_b	Pave	N_a	N_b		
0-100	49.8%	38.7%	39.0%	2,736	76,761	11.76	***
100-200	65.4%	50.2%	50.6%	1,688	74,965	12.34	***
200-300	76.3%	56.7%	57.0%	646	43,171	9.99	***
300-400	77.6%	61.9%	62.2%	505	34,898	7.21	***
400-500	85.8%	67.0%	67.3%	494	34,606	8.86	***
500-	73.5%	68.6%	68.7%	741	51,451	2.87	**
Total	63.5%	54.4%	54.6%	6,810	315,852	14.79	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

2) Freight with Delivery Time Specified

More sophisticated freight services such as just-in-time transport and time-specified delivery have been advancing, enabling freight to be transported so as to arrive at a time adjusted to a factory's manufacturing processes, or during lunchtime or evening shopping hours. Figure 4 shows the percentage of freight in terms of delivery time specification: (1) hour specified, (2) AM or PM specified, (3) date specified, and (4) not-specified. The percent of freight with the hour specified has increased by 1.5 points during the ten years between 1995 and 2005. Agriculture and Fishery shows the highest percentage of hour specified freight among the nine freight types, with 19.2% of shipments designated as such.

We established a hypothesis that hour specified freight is more likely to be transported via expressway, which are known to be more travel time reliable, as such freight is not allowed any delay in delivery. The hypothesis was tested by comparing the ratio of expressway use of hour specified freight and that of not-specified freight in Agriculture and Fishery. As shown in Figure 5, hour specified freight indicated greater ratios of expressway use over all distance categories except 400-500km. As shown in Table 4, a Z-test revealed that the ratio of expressway use for hour specified freight was statistically higher than that of not-specified freight at a significance level of 0.1% over all distance categories except 300-400km and 400-500km. This result suggests that expressways are used at a greater rate when hour specified freight is transported.

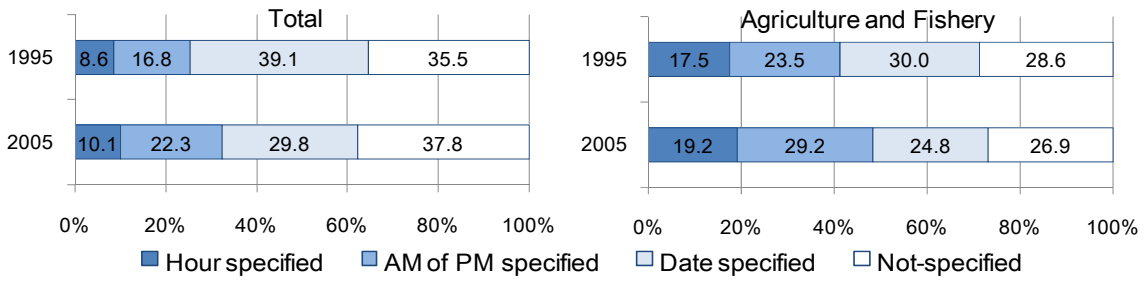


Figure 4 Percentage of freight in terms of delivery time specification
(Left: Sum of the nine freight types, Right: Agriculture and Fishery)

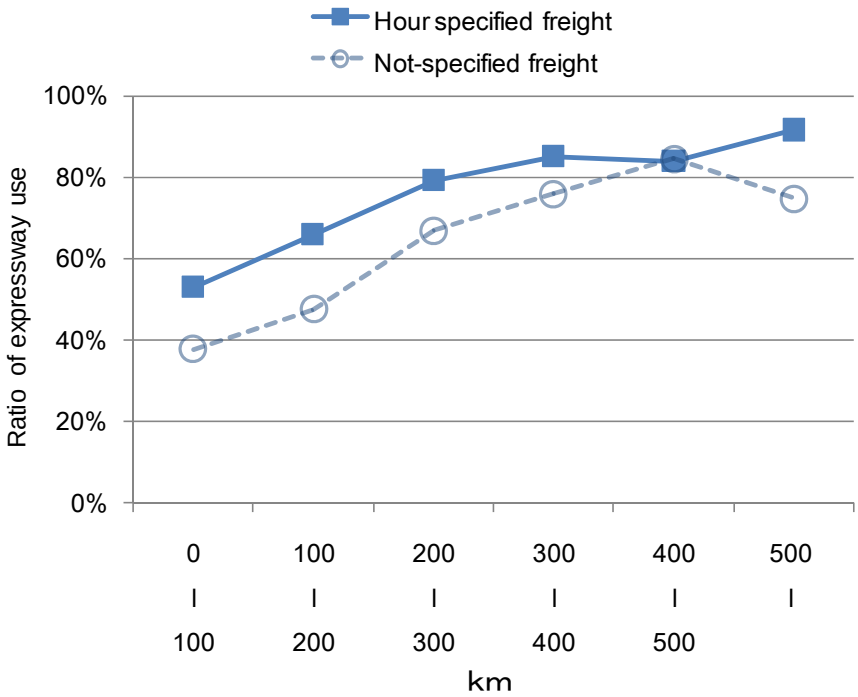


Figure 5 Ratio of expressway use
(Hour specified freight v.s. Not-specified freight)

Table 4 Result of significance test

km	Ratio of expressway use			Number of sample		Z value	
	P_a	P_b	Pave	N_a	N_b		
0-100	53.1%	37.9%	47.6%	911	515	5.54	***
100-200	66.0%	47.6%	60.0%	911	435	6.44	***
200-300	79.3%	66.9%	74.7%	454	272	3.71	***
300-400	85.1%	75.9%	81.3%	202	141	2.17	*
400-500	84.1%	84.6%	84.3%	113	117	-0.11	
500-	91.6%	74.7%	87.8%	597	174	6.00	***
Total	70.9%	55.6%	65.7%	3,188	1,654	10.59	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

a: Hour specifed freight, b: Not-specified freight

3) Small-Lot Freight

Frequency of freight delivery is increasing and the weight of freight shipped simultaneously (freight lot) is decreasing to meet the needs of consignees who prefer that only the necessary amount of freight should be delivered at the most appropriate times in order to reduce unnecessary storage. As shown in Figure 6, average freight lot has halved during the 15 years between 1990 and 2005. Freight lot here is defined as the weight of freight that is shipped as the same kind, at the same time, by the same means of transportation, and to the same destination.

The relationship between freight lot and the ratio of expressway use was analyzed to discuss how the trend of decreasing freight lot influences freight truck route selection. As shown in Figure 7, the smaller the freight lot, the higher the ratio of expressway use; the cause of this trend was inferred from the statistical data shown in Figure 8 and Figure 9. Figure 8 shows the percent of truck types used for freight transport by freight lot category; a: consignors' own trucks, b: forwarders' trucks carrying different items assigned from multiple consignors, c: forwarders' trucks carrying a single item assigned from a single consignor, d: other. The figure shows that the smaller the freight lot, the higher the percent of forwarders' trucks carrying different items (b). Figure 9 shows the average ratio of expressway use for the four truck types; that of forwarders' trucks carrying different items (b) is the highest among them at 62%. Thus, the reason why the ratio of expressway use for small-lot freight is higher is because small-lot freight tends to be transported by forwarders' trucks carrying different items (b), for which we have good evidence of a higher ratio of expressway use.

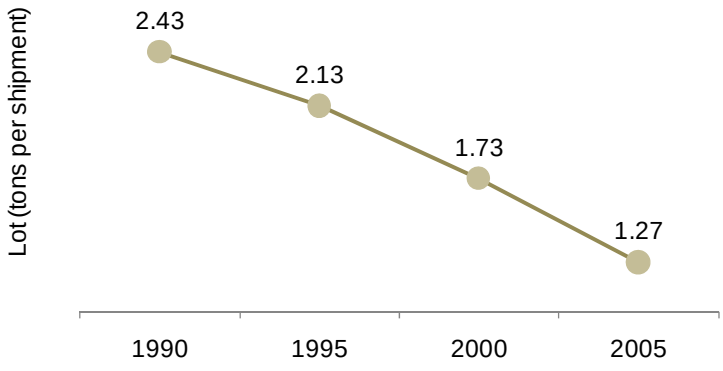


Figure 6 Average freight lot (tons per shipment)

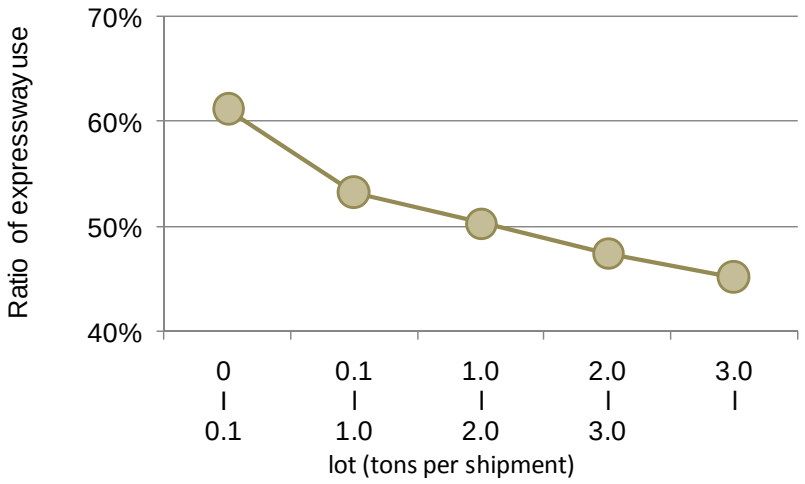
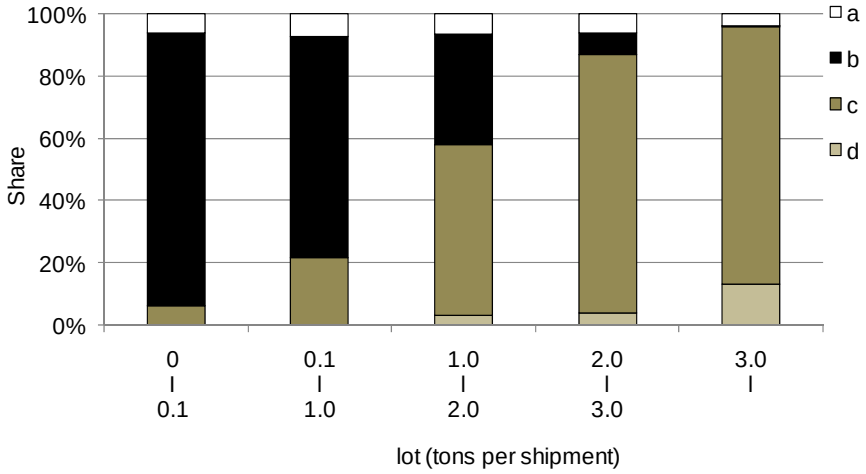


Figure 7 Relationship between freight lot and ratio of expressway use



a: consignors' own trucks
b: forwarders' trucks carrying different items assigned from multiple consignors
c: forwarders' trucks carrying a single item assigned from a single consignor
d: other

Figure 8 Percent of truck types used for transport by freight lot

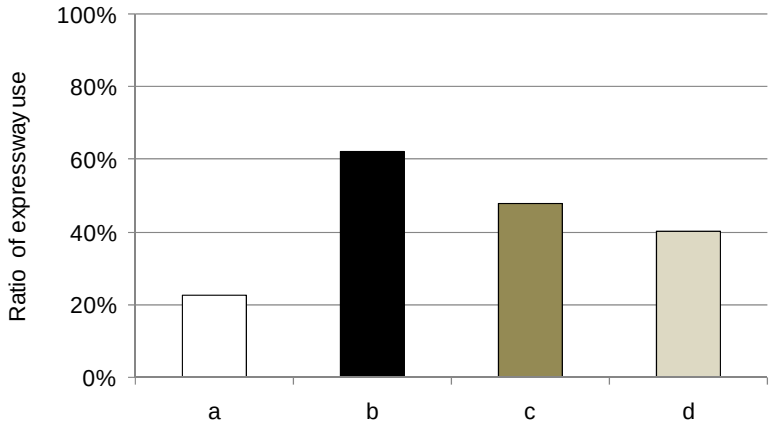


Figure 9 Average ratio of expressway use for the four truck types

4. MODEL PREDICTING THE RATIO OF EXPRESSWAY USE

We developed a model that predicts the ratio of expressway use from the freight characteristics discussed previously. Specifically, the generalized logit model shown in Equation 2 was estimated by regressing the ratio of expressway use to four explanatory variables: (1) transport distance, (2) facility type from which freight is shipped, (3) delivery time specification, and (4) freight lot. Out of 12,127 records in Agriculture and Fishery, the 9,353 records which hold data on all four variables were used for the estimation of the model.

Table 5 shows the estimated regression coefficients of the variables; their signs all agreed with the conditions discussed in the previous chapter, and they all satisfied a 0.1% confidence level. This verifies that all four variables are valid factors that explain the behavior of freight truck route selection.

Plots of the figures predicted by the model are shown in Figure 10. Averaged figures are shown in Figure 11 and Table 6; the maximum difference was 5.6 points at 100-200km, and the accuracy ratio of the model was 0.72.

$$Logit(f) = log\left(\frac{f}{1-f}\right) = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 \quad (2)$$

f : Ratio of expressway use
X1: Transport distance (km)
X2: Facility type from which freight is shipped,
where refrigerator warehouse = 1, other facility = 0.
X3: Delivery time specification, where hour specified =1, not specified = 0.
X4: Freight lot (ton)

Table 5 Estimation results

coefficients	Estimate	Std. Error	Z value	Signif.
(Intercept)	-0.5181533	0.0522113	-9.924	***
Transport distance (km)	0.0050396	0.0001602	31.466	***
Facility type from which freight is dispatched	0.7231309	0.0535702	13.499	***
Delivery time specification	0.207155	0.0513031	4.038	***
Freight lot (ton)	-0.1531429	0.0199895	-7.661	***

AIC: 10858

Number of Fisher Scoring iterations: 5

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Null deviance: 11874 on 9352 degrees of freedom

Residual deviance: 10850 on 9349 degrees of freedom

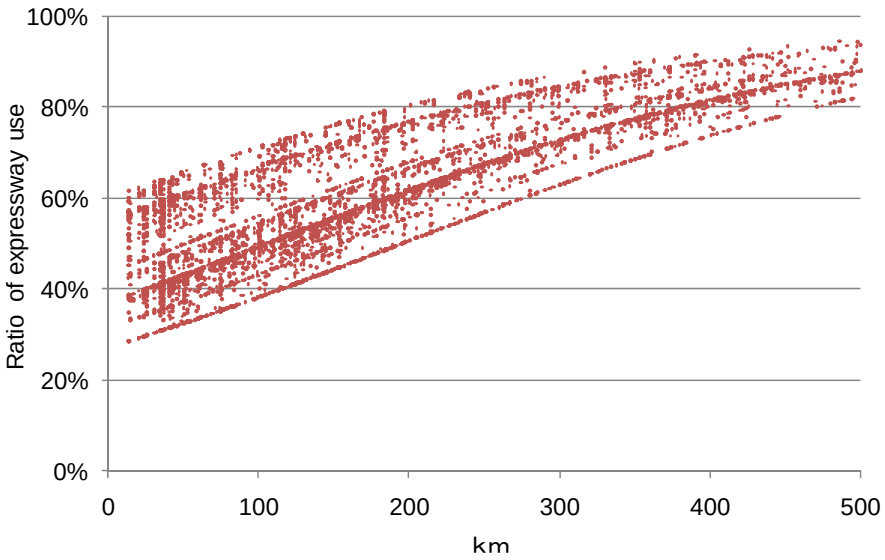


Figure 10 Plots of figures predicted by the model

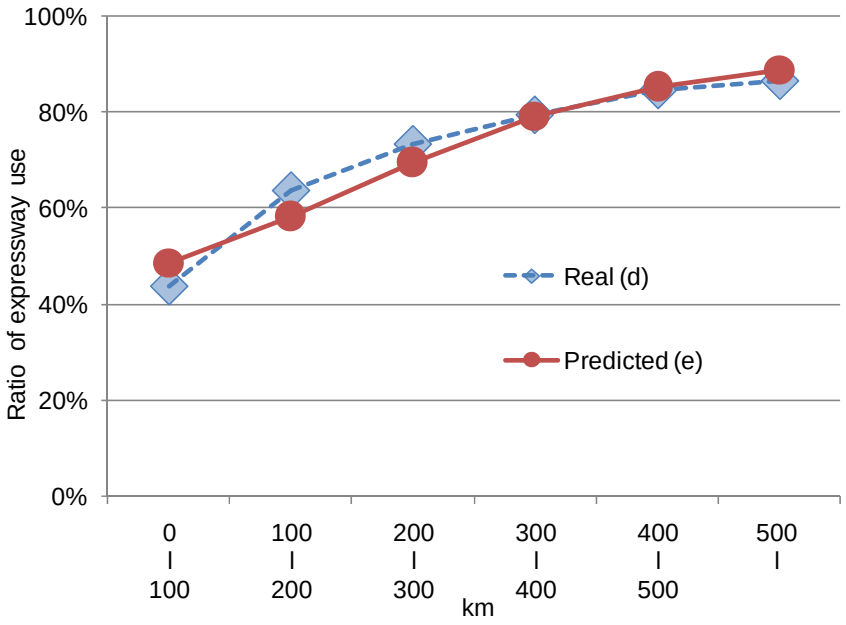


Figure 11 Average ratio of expressway use (real figures / predicted figures)

Table 6 Average ratio of expressway use (real figures / predicted figures)

km	Number of samples			Ratio of expressway use (b/a)		Difference	
	Total (a)	Expressway Use (b)					
		Real	Predicted※	Real (d)	Predicted (e)	e-d (g)	g/d
0-100	2,509	1,095	1,219.9	43.6%	48.6%	5.0%	0.114
100-200	2,259	1,437	1,310.1	63.6%	58.0%	-5.6%	-0.088
200-300	1,230	901	851.7	73.3%	69.2%	-4.0%	-0.055
300-400	881	698	697.2	79.2%	79.1%	-0.1%	-0.001
400-500	433	366	368.4	84.5%	85.1%	0.6%	0.007
500-	2,041	1,762	1,811.8	86.3%	88.8%	2.4%	0.028
Total	9,353	6,259	6,259.0	66.9%	66.9%	-	-

※Accumuration of the predicted f

5. PREDICTION OF CHANGES IN THE RATIO OF EXPRESSWAY USE

We carried out simulations using the model obtained in the last chapter to predict future changes in the ratio of expressway use in the following three cases;

Case 1: Increase in transport distance

Average transport distance and share of freight trucks even in long distance categories have increased, as shown in Figure 12 and Figure 13. This trend is expected to continue due to the advantages freight trucks have in door-to-door transport and at-any-time transport in consideration of demand for more sophisticated freight service. Case 1 simulates conditions in which the transport distance of each freight shipment is increased by 50%.

Case 2: Increase in the number of freight with delivery time specified

As shown in Chapter 3 (2), an increase in the percent of freight with delivery time specified is expected. Case 2 simulates conditions in which each freight shipment is hour specified.

Case 3: Decrease in freight lot

As shown in Chapter 3 (3), the trend of decreasing freight lot is expected to continue. Case 3 simulates conditions in which freight lot decreases to 50%.

The results of the simulations are shown in Figure 14 and Table 7, where Case 0 represents the figures predicted from the actual records in the previous chapter. The predicted ratio of expressway use for Cases 1, 2, and 3 were up, 7.4, 2.6, and 0.7 points from Case 0, respectively. Case 3 yielded only a slight change; change in lot does not affect the ratio of expressway use as much as transport distance and delivery time specification.

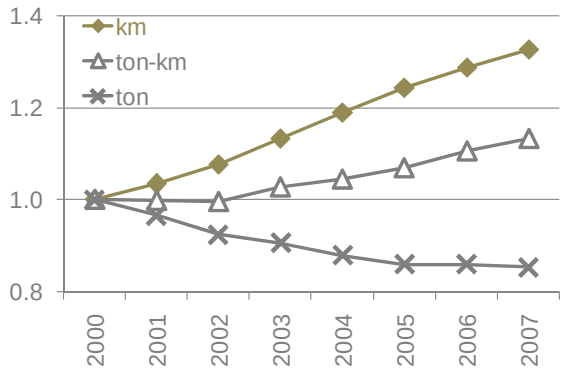


Figure 12 Average transport distance of freight trucks (ratio to the year 2000 figure)

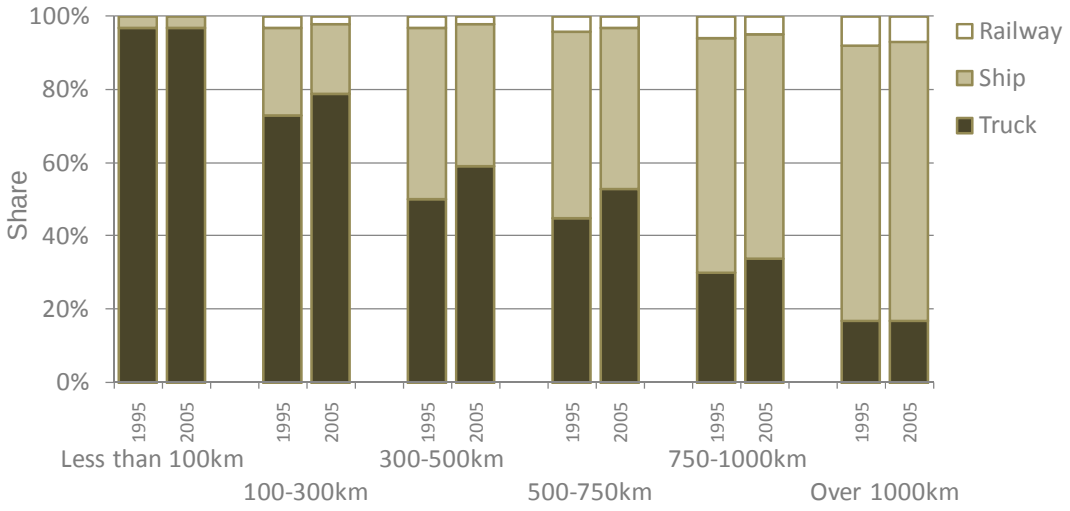


Figure 13 Share of means of transportation by distance category in the years 1995 and 2005

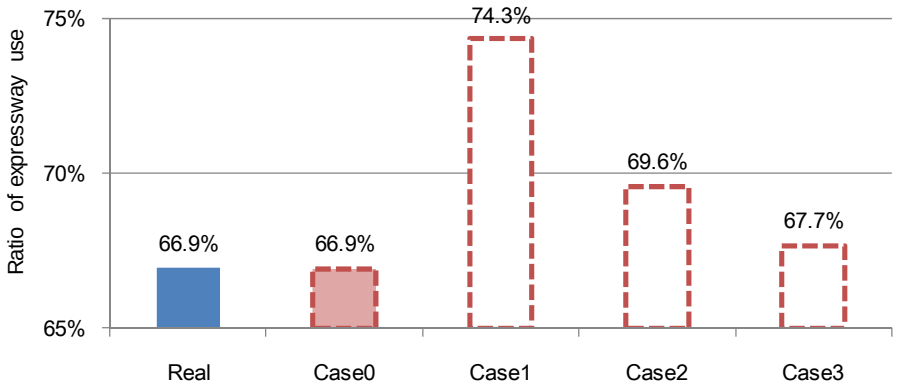


Figure 14 Ratio of expressway use (simulation results)

Table 7 Ratio of expressway use (simulation results)

km	Number of sample		Accumuration of the predicted f (b)				Difference from Case0		
	Total (a)	Real	Case0	Case1	Case2	Case3	Case1	Case2	Case3
0-100	2,509	1,095	1,219.9	1,297.4	1,303.8	1,247.3	77.6	83.9	27.4
100-200	2,259	1,437	1,310.1	1,496.1	1,378.9	1,330.8	186.0	68.7	20.7
200-300	1,230	901	851.7	987.2	889.2	859.3	135.5	37.6	7.7
300-400	881	698	697.2	792.4	718.7	701.3	95.3	21.5	4.1
400-500	433	366	368.4	409.1	376.4	370.2	40.7	8.0	1.8
500-	2,041	1,762	1,811.8	1,969.8	1,839.0	1,819.8	158.0	27.2	8.1
Total	9,353	6,259	6,259.0	6,952.0	6,505.9	6,328.8	693.0	246.9	69.8

km	Ratio of expressway use (b/a)					Difference from Case0		
	Real	Case0	Case1	Case2	Case3	Case1	Case2	Case3
0-100	43.6%	48.6%	51.7%	52.0%	49.7%	3.1	3.3	1.1
100-200	63.6%	58.0%	66.2%	61.0%	58.9%	8.2	3.0	0.9
200-300	73.3%	69.2%	80.3%	72.3%	69.9%	11.0	3.1	0.6
300-400	79.2%	79.1%	89.9%	81.6%	79.6%	10.8	2.4	0.5
400-500	84.5%	85.1%	94.5%	86.9%	85.5%	9.4	1.8	0.4
500-	86.3%	88.8%	96.5%	90.1%	89.2%	7.7	1.3	0.4
Total	66.9%	66.9%	74.3%	69.6%	67.7%	**7.4**	**2.6**	**0.7**

6. CONCLUSION

By analyzing the data obtained from the Commodity Flow Census, we discussed the relationship between freight characteristics and the ratio of expressway use and discovered the following:

- The ratio of expressway use for freight shipped from refrigerator warehouses and for freight with delivery time specified is higher than that of other freight.
- The following four factors have a statistically significant influence on freight truck route selection in terms of the ratio of expressway use; the four factors are (1) transport distance, (2) facility type from which freight is shipped, (3) delivery time specification, and (4) freight lot.

The accuracy ratio of the model was 0.72; this was not very high, indicating the need to improve the model. In the future, we must consider other characteristics that serve as factors that can influence the ratio of freight truck expressway use and incorporate them into the model.

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